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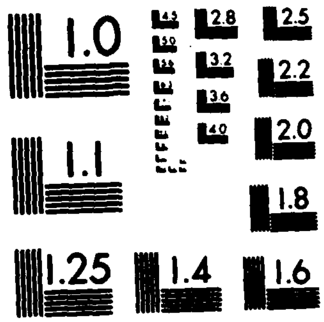

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The main thrust of this research program has been the development and applications of asymptotic and perturbation for analyzing the stability and dynamics of elastic structures and fluid flows. The work is summarized in the papers listed in this report which have been published, accepted for publication, submitted for publication, or are in preparation for publication.

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The Stability and Dynamics of Elastic Structures and Fluid Flows

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Edward L. Reiss
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Principal Investigator

The main thrust of our research program has been the development and applications of asymptotic and perturbation for analyzing the stability and dynamics of elastic structures and fluid flows. The work is summarized in the following papers which have been published, accepted for publication, submitted for publication, or are in preparation for publication.

1. Sinay, L.R., and Reiss, E.L., Perturbed Panel Flutter: A Simple Model, AIAA J., 19 (1981), pp. 1476-1483.

   The effects of small periodic disturbances on the reponse of a two-degree-of-freedom, non-conservative, mechanical system are analyzed. The system is a simple model for panel flutter. The distrubance simulates the pressure fluctuations of a turbulent boundary on the panel. Asymptotic expansions of the solutions are obtained for small amplitudes of the disturbance. The qualitative features of the response depend on the prescribed variation of the frequency of the disturbance with the magnitude of the non-conservative applied force. The disturbance can induce a smooth transition to the fluttering states of the rods; or it may induce jump transitions. The results suggest a possible technique for delaying panel flutter, by imposing a periodic forcing function with an appropriate frequency.

2. Watson, J. G., and Reiss, E. L., A Statistical Theory of Imperfect Bifurcation, SIAM J. Appl. Math., 42 (1982), pp. 135-148.

   An "honest" statistical method is presented to analyze the effects of imperfections, and other disturbances on the bifurcation of solutions of nonlinear problems. First, uniformly valid asymptotic approximations of the solutions are obtained for any realization of the imperfections. The approximations are valid as the magnitude of the imperfections approaches zero. The statistical properties of the solutions are then deduced directly from these approximations, for specified statistics of the imperfections. For simplicity of presentation, the imperfections are taken as zero-mean, wide-sense stationary, Gaussian random processes. The statistical analysis is elementary. It provides easily analyzed results for the expected values and variances of the solutions. Confidence limits are also given.

3. Dellwo, D., Keller, H. B., Matkowsky, B.J., and Reiss, E. L., On the Birth of Isolas, SIAM J. Appl. Math., 42 (1982), pp. 956-963.

   Isolas are isolated, closed curves of solution branches of nonlinear problems. They have been observed to occur in the buckling of elastic shells, the equilibrium states of chemical reactors, and other problems. In this paper, we present a theory to analytically describe the structure of a class of isolas. Specifically, we consider isolas that shrink to a point as a parameter k of the problem, approaches a critical value K_0. The point is referred to as an isola center. Equations that characterize the isola centers are given. Then solutions are constructed in a neighborhood of the isola centers, by a perturbation expansion in a small parameter c, that is proportional to $(k - K_0)^{\alpha}$, with α appropriately chosen. The theory is applied to problems in chemical reactor theory, and nonlinear oscillations.

4. Grotberg, J.B., and Reiss, E. L., A Subsonic Flutter Anomaly, J. Sound and Vibration, 80 (1982), pp. 444-446.

Experiments on the flutter of cylindrical tubes conveying subsonic flows reveal that the tubes first partially collapse into a static; nearly flat state at a critical flow velocity. Then at a second and larger critical flow velocity the tube flutters about this flat state. These results are at variance with existing theoretical studies which show that the nearly flat state loses stability by divergence. In these theories the fluid is assumed to be inviscid and incompressible. We have resolved this anomaly by including fluid damping in the model. Then the nearly flat state loses stability by flutter. It is low frequency flutter for small damping.

5. Strumolo, G., and Reiss, E. L., Poiseuille Channel Flow with Driven Walls, J. Fluid Mech., submitted.

The effects of a prescribed wall motion on the nonlinear stability of Poiseuille channel flow are studied by an asymptotic method. The motion represents a traveling wave in the upper wall of the channel. It can be considered either as a disturbance to the flow that results from experimental imperfections, or as an externally imposed motion. The frequency of this disturbance depends on the Reynolds number of the flow. In the classical Poiseuille channel flow problem, the walls are assumed to be rigid. Then a periodic solution bifurcates from the laminar, Poiseuille flow at the critical Reynolds number, R_c. In the resonance case, the wall motion destroys the bifurcation. The transition from the laminar state then occurs by jumping at new critical Reynolds numbers. These Reynolds numbers either exceed, or are below R_c, depending on the variation of the wall motion frequency with the Reynolds number. Thus the wall motions can stabilize or destabilize the laminar flow, and hence they can be used to control the transition to turbulence. In the non-resonance cases, the bifurcation is preserved and the critical Reynolds number is slightly perturbed.

6. Reiss, E. L., Cascading Bifurcation, SIAM J. Appl. Math., 43 (1983),pp.57-65.

Sequential bifurcation of solutions of nonlinear equations, as the bifurcation parameter increases, is called cascading bifurcation. It has been proposed as a mechanism to describe the transition from laminar to turbulent fluid flows, and as a mechanism for chemical and biochemical morphogenesis and pattern formation. The creation of cascading bifurcation by the splitting of multiple primary bifurcation points is described. A perturbation method is employed in the analysis. Primary, secondary, tertiary, etc. bifurcation points and states are determined for a specific nonlinear boundary value problem.

7. Sinay, L. R., and Reiss, E. L., Secondary Transitions in Panel Flutter: A Simple Model, to be submitted.

A simple, two degree of freedom mechanical model of panel flutter is presented. A perturbation method is employed to determine the secondary bifurcation of flutter states from divergence states, and divergence states from flutter states. The latter suggests a new method for controlling flutter by allowing small amplitude flutter and then increasing the flow velocity until secondary bifurcation into a divergence state occurs.

8. Grotberg, J. B., and Reiss, E. L., Subsonic Flapping Flutter, J. Sound and Vibration, submitted.

A mathematical model of two-dimensional flow through a flexible channel is analyzed for its stability characteristics. Linear theory shows that fluid viscosity, modelled by a Darcy friction factor, induces flutter instability when the dimensionless fluid speed, S, attains a critical flutter speed, S_o. This is in qualitative agreement with experimental results, and it is at variance with previous analytical studies where fluid viscosity was neglected and divergence instability was predicted. The critical flutter speed and the associated critical flutter frequency depend on three other dimensionless parameters: the ratio of fluid to wall damping; the ratio of wall to fluid mass; and the ratio of wall bending resistance to elastance. Non-linear theory predicts stable, finite amplitude flutter for $S > S_o$, which increases in frequency and amplitude as S increases. Both symmetric and antisymmetric modes of deformation are discussed.

9. Magnan, J., and Reiss, E. L., Double-Diffusive Convection and λ-Bifurcation, to be submitted.

We consider convection in a rectangular box where two "substances" such as temperature and a solute are diffusing. The solutions of the Boussinesq theory depend on the thermal and solute Rayleigh numbers R_T and R_s in addition to other geometrical and other fluid parameters. The conduction state is unstable with respect to steady (periodic) convection states if R_s is sufficiently small (large). The boundary between steady and periodic convection occurs at a critical value $R_s = \bar{R}_s$. The linearized theory at $R_s = \bar{R}_s$ is characterized by the frequency $\omega = 0$ appearing as a root of algebraic multiplicity two and geometrical multiplicity one. Asymptotic approximations of the solutions are obtained for R_s near $\bar{R}_s$ by the Poincare-Linstedt method. It is found that a periodic (steady) solution bifurcates supercritically (subcritically) from the conduction state at $R_T = R_T^p(R_T^s)$, where $R_T^p < R_T^s$. The periodic branch joins the steady branch with an "infinite period bifurcation" at $R_T = R_b$, where $R_T^p < R_b < R_T^s$. The shape of the resulting bifurcation diagram suggests the term, bifurcation. The infinite periodic bifurcation corresponds to a heteroclinic orbit in the appropriate amplitude phase plane. The periodic (steady) convection states are stable (unstable), as we demonstrate by solving the initial value problem employing the multi-scale method.

10. Erneux, T., and Reiss, E. L., Brussellator Isolas, SIAM J. Appl. Math., in press.

The Brussellator is a simple chemical model describing pattern formation by bifurcation of solutions. For a one-dimensional system, the bifurcation parameter is related to the ratio of the square of the size of the system to a diffusion coefficient. It has been observed from numerical computations, that there are closed branches of steady state solutions, which are called isolas, that connect neighboring bifurcation points. In addition, these isolas depend on a parameter B. As B approaches a critical value B^o the neighboring bifurcation points coalesce, so that the isola shrinks to a point. We employ a perturbation method to obtain asymptotic expansions of the isolas for B near B^o. Implications of the results for pattern formation are discussed.

11. Erneux, T., and Reiss, E. L., Splitting of Steady Multiple Eigenvalues May Lead to Periodic Bifurcation, SIAM J. Appl. Math., accepted.

A general bifurcation problem is considered that depends on two parameters in addition to the bifurcation parameter λ. It is assumed that all primary bifurcation states correspond to steady solutions and that they branch supercritically. Then it is shown that for a range of system parameters, and near a triple primary bifurcation point the following cascade of bifurcations from the minimum primary bifurcation state is possible. As λ increases there is secondary and then tertiary bifurcation to steady states, and finally Hopf bifurcation at a quarternary bifurcation point. Related transitions have been observed experimentally in thermal convection and other hydrodynamic stability problems. In addition, we show that Hopf bifurcation near a double primary bifurcation point is not possible when both primary states near the double point bifurcate supercritically. However, it is possible near such a double bifurcation point if imperfections are included in the formulation, as we demonstrate.

12. Kriegsmann, G. A., Radiation Conditions for Wave Guide Problems, SIAM Sci. Stat. Comput., 3 (1982), pp. 318-326.

An incident mode propagates down a two-dimensional wave guide until it strikes a localized obstruction which creates reflected and transmitted waves. The numerical determination of these waves is difficult because the classical radiation condition does not apply for an infinite wave guide. In this note we derive a sequence of "localized radiation conditions" which can be applied a few wavelengths away from the scattering object. These conditions allow us to numerically solve the Helmholtz equation on a finite domain.

13. Kriegsmann, G. A., Exploiting the Limiting Amplitude Principle to Numerically Solve Scattering Problems, Wave Motion 4 (1982), pp. 371-380.

A numerical method for solving reduced wave equations is presented. The technique is basically a relaxation scheme which exploits the limiting amplitude principle. A modified radiation condition at "infinity" is also given. The method is tested on two model problems: the scattering of plane shallow water waves off shoals and the scattering of plane acoustic waves off a sound-soft cylinder imbedded between two homogeneous but different half spaces. The numerical solutions exhibit correct refractive and diffractive effects at moderate frequencies.

14. Magnan, J. F., and Goldstein, R. A., Perturbed Bifurcation of Stationary Striations in a Contaminated, Nonuniform Plasma, SIAM J. Appl. Math., 43 (1983), pp. 16-30.

A cylindrical, weakly ionized and collision ·minated neon plasma can be described by a system of nonlinear, parabolic reaction-diffusion equations for the electron and metastable atom axial densities. The equations exhibit a bifurcation from a uniform to a striated state at a critical length of the plasma column. The sharp transition between states predicted by the theory is in contrast with the smooth transition observed in experiments. We apply the theory of singular perturbation of bifurcations to show that small inhomogeneities in the plasma, such as those caused by nonuniform heating and contamination, are sufficient to qualitatively explain the experimental results. We observe that a steady, axial magnetic field in the plasma can also produce a smooth transition.

15. Magnan, J. F., and Huerta, M. A., Spatial Structures in Plasmas with Metastable States as Bifurcation Phenomena, Physical Review A, 26 (1982), pp. 539-555.

The formation of orderly, steady, spatial structures in rf-heated plasmas that have metastable states is studied as the development of an instability of the solution to the reaction-diffusion equations for the plasma species. Plasma-species (electrons, ions, and metastable atoms) source functions are given in terms of the electron energy distribution in strong electric fields and of the various collision cross sections. The methods of two-time expansions and bifurcation theory are used to calculate the non-uniform states that bifurcate from the unstable uniform steady state for straight and toroidal tubes. The sinusoidal density variations give the discharge the appearance of glowing balls of gas. This pattern formation is analogous to the morphogenesis found in certain chemical reactions and biological processes.

16. Grotberg, J. B., Louhi, B., and Reiss, E. L., Secondary Bifurcation of Quasiperiodic Solutions Can Lead to Period Multiplication, submitted.

It is shown using perturbation and asymptotic methods that secondary bifurcation of quasi-periodic solutions from periodic solutions occurs for a model problem. The model is a coupled system of two van der Pol-Duffing oscillators. For special values of the detuning parameters the secondary states are periodic. Then periodic multiplication of solutions can occur at the secondary bifurcation point.

17. Kriegsmann, G. A., and Reiss, E. L., Low Frequency Scattering by Local Inhomogeneities, SIAM J. Appl. Math., 43 (1983).

An asymptotic expansion which is uniformly valid in space is obtained for the low frequency scattering of a plane wave incident on a localized inhomogeneity. The scattering region, which may be simply or multiply (collection of scatterers)connected, has a characteristic length which is small compared with the wave length of the incident wave. The index of refraction n is unity outside the scattering region and it is arbitrary inside the region. The method of matched asymptotic expansions is used in the analysis. The Born approximation is shown to agree with the uniform expansion in the far and the near fields. The leading term in the uniform expansion is a linear functional of $1 - n^2$. Thus, statistics of the scattered field are easily evaluated from the statistics of n, when n is a random process. The method is then applied to the low frequency scattering of an acoustic plane wave by localized inhomogeneities in the density and the index of refraction. Finally, the scattering by a plane which is acoustically hard except for a small impedence spot, is analyzed by the same method.

18. Olmstead, W. E. and Davis, S. H., Stability and Bifurcation in a Modulated Burgers System, Quart. of Appl. Math., 39 (1981), pp. 467-477.

The stability of the null state for a nonlinear Burgers system is examined. The results include (i) an energy estimate for global stability for states involving arbitrary modulation in time, and (ii) an analysis of the bifurcation from the null state for slow modulations. For the slow modulations it is determined that the amplitude $A(\tau)$ of the bifurcated disturbance velocity satisfies a Landau-type equation with time-dependent growth rate $\theta(\tau)$. Particular attention is given to periodic and quasiperiodic modulations of the system, which lead to analogous behavior in $\theta(\tau)$. For each of these oscillatory-type modulations, it is found that $A^2(\tau)$ has the same long-time mean value as the unmodulated case, implying no alteration of the final mean kinetic energy. Applications to various fluid-dynamical phenomena are discussed.

19. Morawetz, C. A., and Kriegsmann, G. A., The Calculations of an Inverse Potential Problem, SIAM J. Appl. Math., 43 (1983).

A method is developed for solving an inverse problem for the wave equation with potential where the object is to find the potential given Cauchy data on a time-like surface. The computation is carried out with one space variable by an iterative procedure. The point of this method is that it can be extended to higher dimensions in principle. A coarse mesh finite difference scheme is used which yields fair accuracy.

20. Kriegsmann, G. A., and Reiss, E. L., Acoustic Propagation in Wall Shear Flows and the Formation of Caustics, submitted.

The propagation of acoustic waves from a high frequency line source in a two dimensional parallel shear flow adjacent to a rigid wall is analyzed by a ray method. The leading term in the resulting expansion is equivalent to the geometrical acoustics theory of classical wave propagation. It is shown that energy from the source is radiated either directly to the far field, or by first reflecting from the wall. In addition, energy is trapped in a channel adjacent to the wall and downstream from the source. The rays in this channel form an infinite sequence of caustics progressing downstream. Since the geometrical acoustics approximation is invalid on and near caustics, a boundary layer method is employed to determine the acoustics field near the caustics. It is shown that the amplitude of the field on and near the caustics is $k^{2/3}$ larger than the geometrical acoustics field for large k. Here K is a dimensionless wave number of the source. Moreover, the vorticity of the acoustics field in the caustic regions is $k^{7/6}$ larger than the geometrical acoustics field. The possible significance of these results for vehicle self-noise and the formation of turbulent spots in the sub-layer of a turbulent boundary layer is discussed.

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